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Intentional communication: solving methodological issues to assigning first-order intentional signalling

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ABSTRACT

Intentional signalling plays a fundamental role in human communication. Mapping the taxonomic distribution of comparable capacities may thus shed light on the selective pressures that enabled the evolution of human communication. Nonetheless, severe methodological issues undermine comparisons among studies, species and communicative modalities. Here, we discuss three main obstacles that hinder comparative research of 'first-order' intentional signalling (i.e. voluntary signalling in pursuit of a cognitively represented goal): (*i*) inconsistency in how behavioural hallmarks are defined and operationalised, (*ii*) testing of behavioural hallmarks without statistical comparison to control conditions, and (*iii*) bias against the publication of negative results. To address these obstacles, we present a four-step scheme with 20 statistical operational criteria to distinguish between non-intentional and first-order intentional signalling. Our unified scheme applies to visual and audible signals, thereby validating comparison across communicative modalities and species. This, in turn, promotes the generation and testing of hypotheses about the evolution of intentional communication.

Key words: first-order intentional signalling, intentionality, gestural communication, vocal communication, pre-linguistic infants, language evolution, animal communication, ostensive communication, visual communication, audible communication

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I. INTRODUCTION

Humans use sophisticated communication that seems unrivalled in the animal kingdom (Tomasello, 2008; Scott-Phillips, 2015*b*). One cluster of fundamental mechanisms which facilitate this sophistication is intentional communication: the ability to signal intentionally and to express and interpret communicative intentions (Grice, 1957; Sperber, 1994). These cognitive abilities enable virtually open-ended flexibility by allowing every act to be loaded with a communicative meaning, and to load the same act with different meanings according to the communicative intentions that are being expressed (Sperber, 1994; Scott-Phillips, 2015*a*). For example, raising an empty glass can be a non-communicative examination of its cleanliness, but the same physical act becomes a communicative request for a refill or an invitation to toast once it is accompanied by a look toward a recipient. Philosophers of language, linguistics and comparative psychologists thus agree that intentionality is a key mechanism in human communication (Grice, 1957; Dennett, 1983; Sperber, 1994; Tomasello, 2008; Scott-Phillips, 2015*b*; Townsend *et al.*, 2017).

Understanding the taxonomic distribution of comparable capacities is crucial to shedding light on the evolution of human communication (Liebal *et al.*, 2014; Townsend *et al.*, 2017). For instance, scholars relied on evidence that non-human great apes gesture but do not vocalise intentionally, to develop the hypothesis that human language evolved *via* the gestural modality (Tomasello, 2008). However, recent evidence for intentional vocal communication in chimpanzees (*Pan troglodytes*) questions this idea (Liebal *et al.*, 2014; Schel *et al.*, 2013). This controversy emphasises the urgent need to improve methodologies distinguishing between non-intentional signalling and even basic forms of intentionality to allow valid comparisons across species and communicative modalities (Townsend *et al.*, 2017; Graham *et al.*, 2019).

Here, we present a unified operational-level scheme to distinguish between non-intentional and 'first-order' intentional signalling across species and the audible and visual communicative modalities. We focus on these modalities as they include modes of communication that have been speculated to be the origin of human language (i.e. vocal and gestural: Tomasello, 2008). In the following introductory sections, we first outline the boundaries of our scheme by differentiating between intentional signalling and ostensive communication. Second, we contrast the mechanistic *versus* intentional explanations for the mechanism which underlies a signalling behaviour. Third, we discuss methodological flaws that hinder reliable inference and systematic comparison of intentional signalling and how they are addressed by the scheme.

(1) Intentional and ostensive communication

The term intentional communication is frequently used to refer to overlapping, yet different, capacities (Ullrich, Mittelbach & Liebal, 2020). Comparative psychologists, who study non-human species, commonly use the term to describe voluntarily signalling in pursuit of a cognitively represented goal (hereafter 'intentional signalling': Scott-Phillips, 2015*b*). Developmental psychologists, who study pre-linguistic children, often add that the signaller should understand the recipient as an intentional agent (Coggins & Carpenter, 1981; Carpenter, Nagell & Tomasello, 1998). Philosophers of language, who focus on adult humans, refer to intentional communication as a mutual mindreading process in which interlocutors express and interpret each other's communicative intentions (i.e. ostensive communication: Scott-Phillips, 2015*b*). Intentional signalling in the sense that is used in comparative psychology is, therefore, a prerequisite for the intentional and ostensive communication that are discussed in developmental psychology and philosophy (Coggins & Carpenter, 1981; Liebal *et al.*, 2014). As efforts are still being made to distinguish reliably between non-intentional and intentional signalling in animals (Townsend *et al.*, 2017; Graham *et al.*, 2019), the current paper focusses on the more fundamental level of intentional signalling.

Following the work of previous scholars that have pinpointed important attributes of intentionality, we define 'first-order' intentional signalling (Dennett, 1983) as *voluntary signalling* (e.g. Tomasello & Call, 1997; Carpenter *et al.*, 1998; Liebal *et al.*, 2014; Townsend *et al.*, 2017) *in pursuit of a cognitively represented goal* (e.g. Bates, 1979; Coggins & Carpenter, 1981; Dennett, 1983; Tomasello & Call, 1997; Carpenter *et al.*, 1998; Liebal *et al.*, 2014; Scott-Phillips, 2015*b*). 'In pursuit' links the signalling with the cognitively represented goal, meaning the signaller believes the signalling is a means to realise her goal (see Section II.2 for goal-directness).

Contrary to traditional definitions (e.g. Dennett, 1983; Ullrich *et al.*, 2020), our definition remains neutral about whether the signaller believes that her signalling realises the goal by affecting the intentional state of the recipient or by other means (e.g. the signaller perceives the recipient as an inanimate object that needs to be operated). We thereby aim to lay the foundations for a layered framework to investigate intentional communication, in which first-order intentional signalling is a necessary, but not sufficient, building block for higher-order intentional communication. For example, demonstrating first-order intentional signalling is necessary to demonstrate second-order intentional signalling (i.e. defined as first-order + the signaller believes her signalling affects the intentional state of the recipient). Using our scheme to show first-order intentional signalling thus does not mean that the subject is incapable of higher-order intentional communication.

(2) Mechanistic *versus* intentional explanations of signalling

Our scheme aims to determine whether the production of a specific signal is more likely to be based on non-intentional or intentional mechanisms. To this end, it contrasts the

'mechanistic' *versus* the 'intentionality' explanations as alternatives (Dennett, 1983; Liebal *et al.*, 2014). The mechanistic explanation postulates that the examined signal evolved as a specific behavioural solution to a specific 'problem' (Harman, 1983; Vail, Manica & Bshary, 2013) and that signalling requires no mental state in the signaller (i.e. 'zero-order' intentionality: Dennett, 1983; Townsend *et al.*, 2017). Vervet monkeys (*Chlorocebus pygerythrus*), for instance, give different alarm calls when detecting a leopard or an eagle (Wegdell, Hammerschmidt & Fischer, 2019). Natural selection may hardwire the triggering of these specific calls upon the perception of specific predator types since they benefit the signaller or its kin (Zahavi & Zahavi, 1997). Since such signals evolve as specialist solutions, their most important hallmark is lack of flexibility regarding when and how they are executed (Dennett, 1983; Liebal *et al.*, 2014).

By contrast, the intentional explanation postulates that the signaller has at least some voluntary control over the signalling and a belief that it is a means to realise her goal (Dennett, 1983; Liebal *et al.*, 2014). These physiological and cognitive capacities enable the key characteristics which allow inferring intentional signalling: (*i*) adjustability (i.e. dynamic adjustment to the recipient's response and the environmental and social conditions), and (*ii*) generality (i.e. intentionality underlies the production of various signals of the species).

As pointed out by Dennett (1983), each of the behavioural hallmarks that are traditionally used to infer intentionality can be explained by mechanistic processes. Even demonstration of several hallmarks of intentionality in the same signal can be explained by a combination of mechanistic processes [e.g. genetically hardwired signalling that is elaborated through conditioning (Fischer & Price, 2017; Schnell *et al.*, 2021)]. Prominent scholars have thus argued that a definitive test to distinguish between non-intentional and intentional signalling in animals may not be possible (Dennett, 1983; Liebal *et al.*, 2014; Townsend *et al.*, 2017). Instead, they call for the presentation of 'converging' evidence that makes intentionality the more plausible and parsimonious explanation than the mechanistic one. This rationale is summarised in what can be called the 'plausibility argument'.

(1) There is a certain probability for the emergence (in evolution/ontogeny) of each mechanism that adjusts a signalling behaviour to the circumstances.
(2) There is no reason to believe that the emergence of one mechanism increases the probability of additional mechanisms to evolve.

From these two points can be derived an intermediate conclusion: the probability that several mechanisms would evolve to produce highly adjustable signals decreases with the number of mechanisms involved.

(3) First-order intentional signalling requires voluntary control over signalling and a belief that the signalling is a means to realise the goal.
(4) Voluntary control and believing that signalling behaviours are a means to realise one's goals enable high adjustability of various signalling behaviours.

Together, these four points allow a final conclusion: the more different hallmarks of adjustability are demonstrated in different signalling behaviours of a species, the greater the probability that these signals are facilitated by intentionality rather than a combination of several non-intentional mechanisms.

Accordingly, for any particular signal, the scheme favours the intentionality over the mechanistic explanation upon (*i*) demonstration of numerous hallmarks of intentionality in the tested signal (i.e. adjustability); which is also combined with (*ii*) demonstration of intentionality in at least two signals from the same communicative modality of the species (i.e. generality). Being from the same communicative modality ensures substantial evidence for intentionally in this modality since voluntary control over one modality does not necessarily entail the same in other modalities.

(3) Obstacles to inference and systematic comparison of first-order intentional signalling

Three main obstacles hinder valid inference and systematic comparison of intentionality in animals. First, inconsistency in how hallmarks of intentionality are defined and operationalised prevents systematic comparison among studies, species and communicative modalities (Liebal *et al.*, 2014; Graham *et al.*, 2019). Progress toward uniformity has recently been made in the framework developed by Townsend *et al.* (2017). However, this framework focuses on the defining conditions of first-order intentionality and is not meant to overcome inconsistency at the operational level (Graham *et al.*, 2019). For instance, the framework of Townsend *et al.* (2017) suggests inferring goal-directed signalling by assessing elaboration of signalling. But little is said about what exactly constitutes elaboration and how it should be tested. Our scheme facilitates systematic comparison by addressing this operational level. To this end, we reviewed empirical studies on pre-linguistic human children and animals, selected the most rigorous operational criteria (see remarks for each criterion) and adjusted them for audible and visual signals.

Second, behavioural hallmarks are often examined without statistical comparison to control conditions (Graham *et al.*, 2019). This is manifested in two ways: (*i*) a hallmark of intentionality is considered to be fulfilled if it was exhibited in the majority of signalling events (e.g. Pika & Bugnyar, 2011). Such operationalisation, however, does not test whether the behaviour examined is indeed a manifestation of the hallmark or not. For instance, testing whether the 'response-waiting' hallmark is exhibited in the majority of events (e.g. manifested by a post-signalling pause of at least 2 s while maintaining visual contact with the recipient: Fröhlich *et al.*, 2016) leaves untested the possibility that the observed pause is used to rest after many similar behaviours,

rather than waiting for a response. (*ii*) Studies on gestural repertoire often use a 'filtering approach', in which a data set of signalling events is filtered to include only events that exhibit one/few hallmarks of intentionality (e.g. Genty *et al.*, 2009; Hobaiter & Byrne, 2014). Focusing on the level of a signalling event, however, prevents statistical comparison with control conditions. Moreover, since some events of non-intentional signalling may exhibit hallmarks of intentionality for other reasons, filtering approaches are likely to find alleged events of intentionality in almost any data set of a given signal and, therefore, to qualify the signal as intentional (type I error). For example, if response-waiting is defined as a post-signalling pause longer than 2 s, some 'response-waiting' events may be found even if the examined species exhibits a skewed distribution of post-signalling pauses in which most events lack any pause (Fig. 1; see also operational criterion 1a1 in Section II.2). For these reasons, filtering approaches are not suitable to qualify a signalling behaviour as first-order intentional, although they may be used in follow-up studies once the signal or a specific communicative modality of the species has been qualified as intentional.

To allow more rigorous testing of behavioural hallmarks, each operational criterion in our scheme was designed to compare episodes statistically with the alleged hallmark against control conditions and/or to test 'adequate manifestation' of the hallmark (see Table 1). In addition, the scheme is designed to test whether the production of *a specific signal* fulfils hallmarks of intentionality across communicative interactions and not necessarily in each signalling event (Table 1). Namely, it focuses on the signal level in order to infer a species' capacity to signal intentionally in a specific communicative modality (e.g. the finding that chimpanzees produce a specific type of gesture intentionally suggests that chimpanzees are capable of intentional gestural communication).

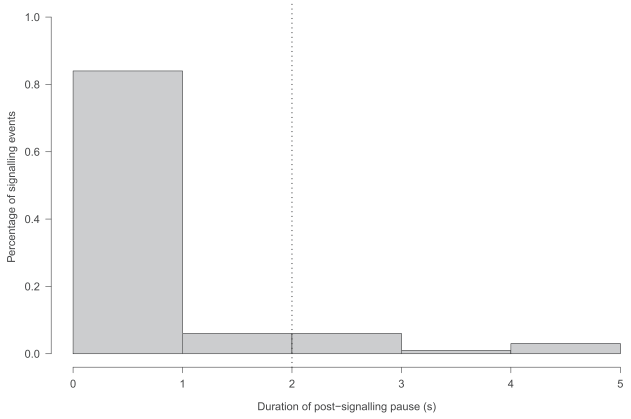

Fig 1. Hypothetical distribution of the duration of pause after the production of signal X. The dotted line represents a defined threshold of response-waiting (i.e. post-signalling pause longer than 2 s). As 10% of signalling events exhibit 'response-waiting', a filtering approach for inference of intentionality will only examine these events and may qualify the production of signal X as fulfilling the response-waiting hallmark. Consequently, it may qualify signal X as intentional, despite exhibiting little evidence for the response-waiting hallmark overall.

Third, there is a bias toward positive results (Liebal *et al.*, 2014) that obstructs the understanding of the taxonomic distribution of intentionality. Species that seem capable of non-intentional signalling only are rarely tested for hallmarks of intentionality and/or studies with negative results are not often published. Species that have been demonstrated to signal intentionally are thus highlighted (e.g. great apes: Ullrich *et al.*, 2020), while it remains unclear whether other species are incapable of intentional signalling or have simply not been tested (e.g. birds). Nonetheless, identifying which species are incapable of intentional signalling in certain/all communicative modalities is essential if the taxonomic map of intentional communication is to be informative for generating and testing hypotheses about its evolution. To facilitate the recognition of negative results, we also present counterevidence for the behavioural hallmarks of intentionality in our scheme. Note that these are counterevidence only for the presence of the hallmark discussed. They, therefore, cannot preclude that the signalling behaviour in question is intentional without additional counterevidence for other behavioural hallmarks.

II. THE SCHEME

Here, we endorse the theoretical framework of Townsend *et al.* (2017) and the three conditions it proposes as necessary to qualify a behaviour as first-order intentional signalling: (*i*) voluntary production, (*ii*) goal-directness and (*iii*) changing the recipient's behaviour in ways that are conducive to realise the signaller's goal (Table 2). As our scheme focuses on the operational level, the reader is referred to Townsend *et al.* (2017) and references in the appropriate places for justification of these conditions. The scheme consists of four operational steps to infer these three conditions. For each condition, we discuss several hallmarks and for each hallmark, we present at least one operational criterion. All hallmarks and operational criteria are formulated in non-specific terms to enable each of them to test audible and visual signals.

The scheme focuses on 'real-time' communication that allows for examining the dynamic correspondence between signalling and immediate response (see Table 1). Non-dynamic signalling (see Table 1) may nonetheless be intentional, but such instances are not fully covered by the scheme.

(1) First step: inferring the signaller's goal through the detection of statistical regularities

This is a preparatory step to test the first and third conditions for first-order intentionality (i.e. goal-directed signalling and that signalling realises the signaller's goal). Following previous authors (e.g. Hobaiter & Byrne, 2014; Townsend

Table 1. Glossary of terms

Term	Definition
An adequate manifestation of a behavioural hallmark	To ensure the realisation of the goal, the behavioural hallmark is adjusted to the dynamic response of the recipient and the environmental and social conditions in which signalling occurs (see examples in each behavioural hallmark).
Real-time communication	Signalling that is aimed at realising a goal promptly. It, therefore, allows examining the dynamic correspondence between signalling and responding. For instance, a gesture aiming to solicit the recipient to follow the signaller (see babbler walk signal in Table 3) or a vocalisation aiming to attract group members to a food source (Vitale *et al.*, 2003).
Non-dynamic signalling	Signalling that is not directed towards a specific recipient, but to any potential recipient that may be or would be present within signalling range. It, therefore, seldom involves real-time correspondence between signalling and responding. Examples include calling by crickets (Forrest, 1982) and light production by fireflies (Lampyridae) to attract potential mates.
Standard complying response (SCR) time unit	The median duration of time from the beginning of signalling until the recipient starts to realise the signaller's goal. An SCR time unit should be calculated for each signal in a specific community and during a specific study.
A failure to realise the signaller's goal has been clearly indicated	When (*i*) the recipient does not start to respond according to the signaller's goal after three SCR time units; or (*ii*) the recipient's behaviour/the environmental conditions have been changed in a way that obstructs the signaller's goal (Bates, 1979). For example, the recipient moves far away from the signaller or a predator appears.
Complying recipient	A recipient that starts to respond within one SCR time unit in a way that realises the signaller's goal and continues to respond until this goal is fully realised (e.g. communicative interaction 6 in Fig. 2).
Non-complying recipient	A recipient that (*i*) does not start to realise the signaller's goal within one SCR time unit (e.g. communicative interactions 2 and 3 in Fig. 2), or (*ii*) stops responding before the signaller's goal is fully realised (e.g. communicative interaction 5 in Fig. 2), or (*iii*) does not respond at all (e.g. communicative interactions 1, 9 and 10 in Fig. 2).
Signalling event	The production of a signal.
Communicative interaction	An interaction that starts at the beginning of the first signalling event and lasts until the signaller's goal is realised or failure to realise the signaller's goal has been clearly indicated.

et al., 2017), the signaller's goal can be evident in the changes in the recipient's behaviour that are followed by a cessation of signalling.

***Operational criterion 1*:** coding all behavioural changes of the recipient throughout various communicative interactions (e.g. stop behaviour X, start behaviour Y), followed by testing which changes are statistically likely to be followed by a cessation of signalling behaviour (Fig. 2).

Remarks: (*i*) behaviours that elicit an aversive response from the signaller should be excluded to rule out changes that despite being a response to signalling and repeatedly ending it, do not represent a plausible outcome for the signaller [e.g. physical aggression towards the signaller (Hobaiter & Byrne, 2014)].

(*ii*) Our operational criterion statistically accounts for all changes in the recipient's behaviour, regardless of whether they were followed by the cessation of signalling. It thereby differs from the 'apparently satisfactory outcome' criterion (Cartmill & Byrne, 2010; Hobaiter & Byrne, 2014), which only considers changes that were followed by cessation of signalling. We consider four advantages to our approach. First, it infers the signaller's goal statistically by comparing the probability of different behavioural changes to terminate signalling. Second, it statistically accounts for changes that were followed by a cessation of signalling by chance (which may have been considered as the 'secondary' or 'tertiary' meanings of a signal by Hobaiter & Byrne, 2014). Third, it can detect more than one behavioural change that is likely to be followed by a cessation of signalling. Fourth, it points out behavioural changes that should not be considered as the signaller's goal.

(*iii*) Inferring the signaller's goal when signalling is not clearly directed towards specific recipients (see hallmarks 1a and 1e for examples) is challenging. This challenge especially applies to audible signals, which can pass through physical obstacles and make it difficult to identify a recipient's response. We thus suggest that signals that are produced in the absence of known recipients and do not receive a real-time response may be non-dynamic communication (see Table 1) that is not addressed by this scheme. To infer the goal of signals that are produced in the presence of potential recipients (e.g. conspecifics, group members, predators) but are not clearly directed towards them, we propose applying operation criterion 1 to some of these potential recipients. An absence of a distinct response by these recipients should be considered as evidence for non-intentional signalling such as, for example, signalling induced by arousal (Liebal *et al.*, 2014; see also Table 2).

Counterevidence for the examined behaviour being a signal: none of the behavioural changes of the audience is statistically likely to be followed by a cessation of 'signalling' behaviour. In this case, what is thought to be 'signalling' may rather be a non-

Table 2. Operational scheme to infer first-order intentional signalling

Condition	Sub-condition	Behavioural hallmark
Goal-directed signalling	Belief criterion*	(1) Absence of response to signalling (see text in step 1 of the scheme)**
		(1a) Adequate response-waiting
		(1b) Adequate elaboration of signalling
		(1c) Adequate interchangeable use of signals
		(1d) Communicative tool use
		(1e) Adjustment of signalling behaviour to the sensory perception of recipients
	Desire criterion*	(1f) Adequate persistence of signalling
Voluntary signalling*	The execution of signalling is not unconditionally triggered by specific stimuli	(2a) Preparation for signalling
		(2b) Behavioural dissociations between the external stimulus and signalling
		(2c) Adequate coupling and decoupling of signals
		(2d) Selective signalling according to the presence of recipients
		(2e) Between-communities interchangeable use of signals
		(1c) Adequate interchangeable use of signals
	The execution of signalling is not completely genetically determined	(2f) Premature termination of signalling behaviour
		Signalling is sex-specific (see remarks in behavioural hallmark 2g)**
		(2h) Selective production/withholding of signalling according to complex conditions
		(1c) Adequate interchangeable use of signals
		(2e) Between-communities interchangeable use of signals
	The form of signalling is not completely genetically determined	(1b) Adequate elaboration of signalling
		(1d) Communicative tool use
		(1e) Adjustment of signalling behaviour to the sensory perception of recipients
Signalling behaviour realises the signaller's goal*		(3) Signalling is likely to change the recipient's behaviour in ways that are conducive to realising the signaller's goal

*To qualify as first-order intentional signalling, a behaviour must fulfil at least one operational criterion from each of the four conditions/sub-conditions with an asterisk. Each behavioural hallmark can be considered once.
**Can only provide evidence against intentional signalling.

communicative behaviour (e.g. foraging behaviour, tool use) or a manifestation of arousal (Liebal *et al.*, 2014).

(2) Second step: inferring goal-directed signalling

Definition of goal-directed signalling: the production of a signal based on two necessary conditions: the signaller (*i*) believes that the signal is a means to realise her goal (belief criterion) and (*ii*) the realisation of the goal is desired by/adaptive for the signaller (desire criterion) (for review see Dennett, 1983; De Wit & Dickinson, 2009).

Belief criterion

Note that first-order intentional signalling describes the intentional state of the signaller only. It does not require perceiving the recipient as an intentional agent, or a true belief about how her signalling realises the goal (Dennett, 1983; De Wit & Dickinson, 2009).

Behavioural hallmark 1a: adequate response-waiting

Response-waiting is a hallmark of expectation that the signalling will affect the recipient (Bates, 1979; De Wit & Dickinson, 2009; Cartmill & Byrne, 2010).

Definition of adequate response-waiting: the signaller monitors the recipient (starting at any point from the onset of signalling until shortly after the first signalling event in the interaction) until the latter starts to respond in ways that realise the signaller's goal or until failure to realise her goal has been clearly indicated (Table 1).

Operational criterion 1a1: testing whether the examined signal is more likely to be followed by response-waiting than a control behaviour is likely to be followed by monitoring the audience's behaviour for at least one SCR time unit (see Table and Fig. 3). 'Control behaviour' is defined as a non-communicative behaviour that is similar to the tested signal (e.g. see object presentation in Table 3).

Example: huu calls in Table 3.

Operational criterion 1a2: testing for correspondence between the recipient's behaviour at the time of being monitored and the signaller's behaviour after the act of monitoring. Namely, whether the signaller adjusts her post-monitoring behaviour to the recipient's behaviour.

Example: babbler walk in Table 3.

Remarks on behavioural hallmark 1a: (*i*) traditional operational criteria of response-waiting require that after signalling the signaller pauses and monitors the recipient's behaviour for a minimum number of seconds (e.g. Cartmill & Byrne, 2010; Graham *et al.*, 2019). Our definition differs from these criteria in three important ways: firstly, monitoring does not have to start after the end of signalling. It may start any time between the onset of signalling and shortly after the end of the first signalling event. This enables testing

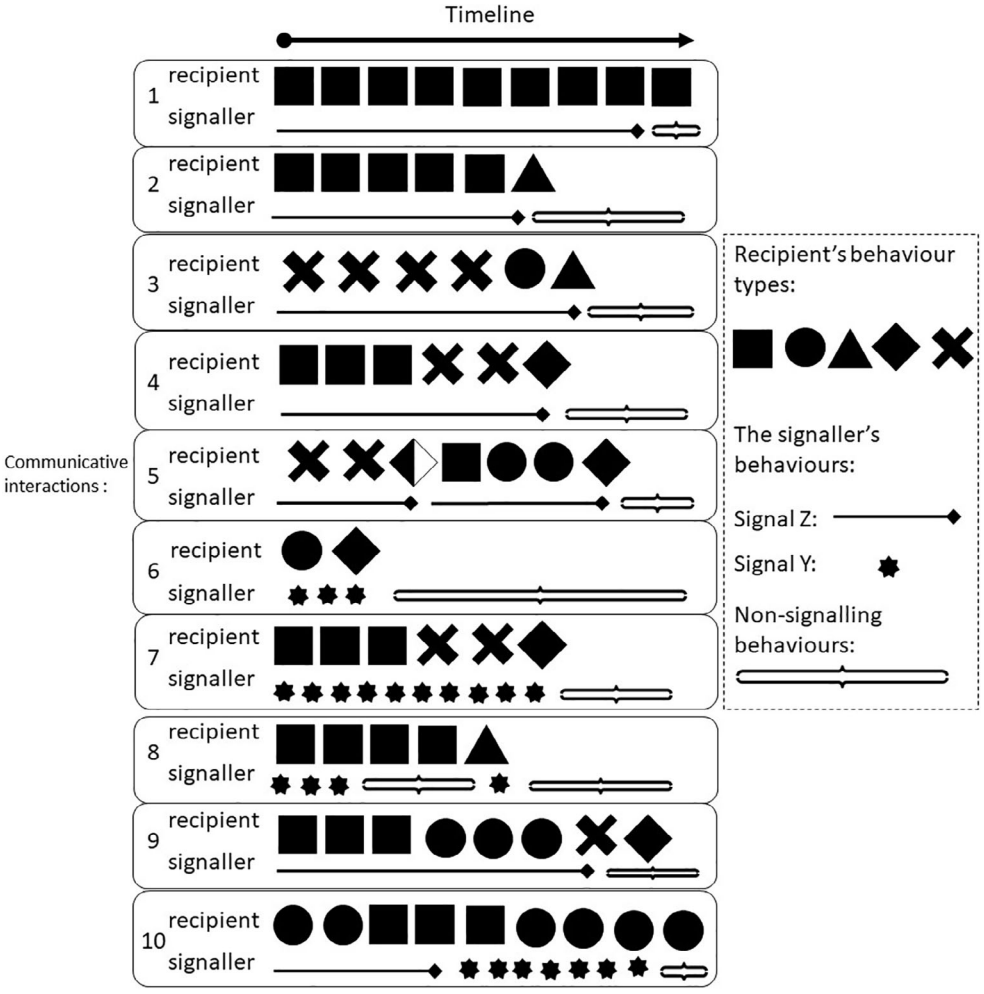

Fig 2. Signalling events in relation to changes in the recipient's behaviour. Across communicative interactions, changes to the 'triangle' and 'rhombus' behaviours are repeatedly followed by a cessation of signalling behaviours Z and Y (in contrast to changes to the 'square', 'X' and 'circle' behaviours). The goals in producing these signals can thus be regarded as changing the recipient's behaviour to the 'triangle' or 'rhombus' behaviours.

signals consisting of one prolonged signalling event that lasts until the recipient realises the signaller's goal or failure has been clearly indicated (e.g. object presentation in Table 3).

Secondly, it does not require a pause from acting. As in humans, non-human animals may be able to communicate while performing other tasks (e.g. vocalising while foraging). A distinct pause, thus, is not a necessary characteristic of expectation. Instead, we highlight the monitoring of recipients as an essential characteristic of expectation.

Thirdly, we emphasise that the duration of monitoring should be adjusted to the recipient's response. In our opinion, a fixed duration of post-signalling monitoring, which is independent of the recipient's response, rather characterises stereotypic behaviours.

(*ii*) Interactions in which the recipient responds at any time between the onset of signalling until shortly after the first signalling event (e.g. within <0.1 SCR time units) should be excluded from the analysis of operational criterion 1a1 since response-waiting is not needed (Genty *et al.*, 2009).

(*iii*) As infants become confident in their signalling, they are less likely to monitor the recipient and may only monitor non-complying recipients (Table 1; Bates, 1979). Hence, our criterion does not require demonstration of response-waiting in most interactions, but that it will be statistically more prevalent after the tested signal than after a control behaviour (Fig. 3).

(*iv*) The way a signaller monitors the recipient is likely to depend on the recipient's common response (Liebal *et al.*, 2014). Visual responses (e.g. approaching the recipient) are more likely to be monitored visually. For example, by gazing at the recipient or frequent head alternations towards the recipient (Bates, 1979; see also babbler walk and huu calls in Table 3). Audible responses (e.g. contact calls) may be monitored audibly (i.e. by remaining quiet and/or raising the head to listen to a reply) but also visually (visual scanning of the surroundings).

(*v*) Monitoring can be discrete or continuous. For instance, visual monitoring may involve discrete head alternations

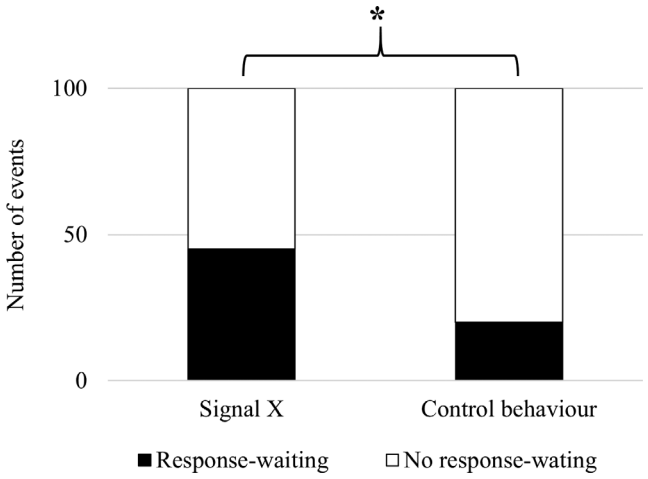

Fig 3. Hypothetical evidence for response-waiting by operational criterion 1a1. Although signallers did not demonstrate response-waiting in the majority of signalling events, they were significantly more likely to monitor the recipient behaviour following the production of signal X (45/100 events) than after a control behaviour (i.e. a non-communicative behaviour that is physically similar to the tested signal; 20/100 events). 80 signalling events in which the recipient responded before the signalling ended were excluded from the analysis.

towards the recipient or continuous gazing at the recipient (compare monitoring in babbler walk with object presentation signals in Table 3). Operational criterion 1a2 is only suitable for discrete monitoring.

(*vi*) Operational criterion 1a2 is only suitable when the signaller's goal requires a prolonged response, during which the signaller may need to adjust signalling or re-engage the recipient before her goal is fully realised (e.g. babbler walk in Table 3).

(*vii*) The focal unit of operational criterion 1a1 is the communicative interaction. Namely, the coded parameter is whether the signaller monitored the recipient's behaviour at any time between the onset of the first signalling event and until the latter starts to realise the signaller's goal (yes/no), regardless of whether the signaller re-signals during this period or not. The focal unit of operational criterion 1a2 is each signalling event, and the coded parameters are the recipient's behaviour when she was monitored, and the signaller's behaviour after each act of monitoring.

(*viii*) Operational criterion 1a2 is superior to criterion 1a1 for two reasons. First, demonstrating that the signaller uses the information that was gathered in monitoring to adjust her next actions confirms that the behaviour defined as 'monitoring' is indeed used to monitor the recipient. Second, it demonstrates continuous adjustability of signalling, which is a key characteristic of intentionality.

Counterevidence for adequate response-waiting being present (examples): (*i*) signallers do not monitor the recipient after signalling; (*ii*) signallers monitor the recipient's behaviour for a fixed duration of time regardless of the behaviour of the recipient; (*iii*) 'monitoring' the recipient's behaviour is likely to follow the production of the signal as much as the control behaviour; (*iv*) signallers continue to wait for a response even if the recipient was experimentally removed (see tandem running in ants in Table 3); (*v*) signallers do not change their post-monitoring behaviour in accordance with the recipient's behaviour.

Behavioural hallmark 1b: adequate elaboration of signalling

Adequate elaboration of signalling demonstrates flexibility in signalling behaviour. Moreover, it suggests an ability for means–end dissociation in response to monitoring of the recipient's behaviour (i.e. believing that the signalling is a 'means' that can be separated from the realisation of the 'end' goal) (Carpenter *et al.*, 1998; De Wit & Dickinson, 2009).

Definition of elaboration of signalling: within a communicative interaction, at least one signalling event differs qualitatively from the others by (*i*) the addition and/or subtraction of a new element in the signal (e.g. adding a vocal element to a gestural signal), or (*ii*) the performance of a completely different signal (i.e. interchangeable use of signals).

Operational criterion 1b (adequate elaboration of signalling): (*i*) testing whether elaboration is more likely to occur in interactions with non-complying recipients than in interactions with complying recipients (Table 1), while (*ii*) employing different forms of elaboration across communicative interactions that are aimed to realise the same goal.

Examples: babbler walk and headstand signals (Table 3).

Remarks: (*i*) elaboration of signalling requires a qualitative change in signalling within the same interaction. By contrast, adequate elaboration of signalling requires that elaboration is selectively applied across communicative interactions.

(*ii*) Quantitative modifications of the signal (i.e. exaggeration) may result from increased arousal due to a continuous stimulus (Liebal *et al.*, 2014). We, therefore, do not consider these as evidence for means–end dissociation.

Counterevidence for adequate elaboration being present (examples): (*i*) the same signal is always used to realise the same goal, even when interacting with non-complying recipients; (*ii*) signalling behaviour is stereotyped (e.g. tandem running in ants in Table 3); (*iii*) elaboration of signalling is not more likely to be used towards non-complying than complying recipients; (*iv*) signalling is always elaborated in the same way.

Behavioural hallmark 1c: adequate interchangeable use of signals

The use of different signals to realise the same goal and/or usage of the same signal to realise different goals demonstrates complex relationships between signal selection and goals (i.e. there is not a one-to-one correspondence between a specific signal and goal; Fig. 4). It thereby suggests means–end dissociation and voluntary control over signalling (Genty *et al.*, 2009; Liebal *et al.*, 2014), especially if signals are implemented to fit different social and environmental contexts adequately.

Table 3. Exemplary analyses of signals (the operational criteria in the examples are often similar, but not identical, to those proposed in our scheme)

Object presentation (Ben Mocha & Pika, 2019)	**Modality:** gestural **Species:** birds – Arabian babbler (*Turdoides squamiceps*) **Description:** a signaller picks an arbitrary object in his/her beak and presents it to an opposite-sex recipient. **Goal:** to solicit the recipient to follow the signaller for copulation where they are hidden from other group members.	**Exemplary operational criteria** **Response-waiting** After starting the presentation, the signaller gazes at the recipient and pauses for more than 3 s or gazes at the recipient and performs her next action only after the recipient responds (e.g. moves towards a hidden location).	**Selective signalling in the presence of specific recipients** Signallers signal only at times and/or locations that are concealed from other group members. If a subordinate member appears during a presentation by the alpha male, the latter stops signalling. As Arabian babblers do not attack more dominant individuals, termination of signalling of dominants is not an involuntary reaction of fear (Ben Mocha *et al.*, 2018).	**Signalling behaviour realises the signaller's goal** Arabian babblers are more likely to bend over in a copulation posture and/or approach a signaller that presents an object than a conspecific that holds a food item during allofeeding interactions (i.e. physically similar control behaviour).
Tandem running in ants (Hölldobler *et al.*, 1974)	**Modality:** tactical and chemical **Species:** ants/diverse species; these examples focus on *Camponotus sericeus* **Description:** a signaller faces a nestmate's head, grasps it on the mandibles and pulls it 2–20 cm forwards. It then loosens the grip, turns around 180° and presents its gaster to the recipient. If the recipient touches the signaller's gaster or hind legs, tandem running starts. During tandem running the following ant frequently touches the leader's hind legs or gaster. The leader drags its abdominal tips over the ground and discharges a short-lived chemical that facilitates the follower's orientation. Tactile signals are sufficient to release normal leadership behaviour during tandem running. **Goal:** to lead a nestmate to a newly discovered nest.	**Exemplary operational criteria** **Elaboration of signalling (counterevidence)** No elaboration as "this behavioural sequence is very stereotyped" (Hölldobler *et al.*, 1974, p. 112). In addition, if the recipient does not follow the recruiting ant, the latter may physically carry it to the desired destination.	**Adjustment of signalling to the recipient's sensory perception and response waiting (counterevidence)** If the leader and follower are separated, the leader waits passively for about 110 s regardless of whether the follower was experimentally removed.	**Dissociations between external stimulus and signalling** A considerable period between finding the new nest and the scout's arrival at its current nest and finding a nestmate to recruit. However, it is not clear whether scouts perform other behaviours between discovering the new nest and returning to recruit a nestmate.

Table 3. *(Cont.)*

Babbler walk (Ben Mocha *et al.*, 2019)	**Modality:** multi-modal (gestural and vocal) **Species:** birds – Arabian babbler (*Turdoides squamiceps*)	**Exemplary operational criteria** **Adjustment of signalling to the recipient's sensory perception**	**Elaboration**	**Persistence of signalling**
	Description: group members perform bouts of wing shivering and/or distinct vocalisation towards dependant fledglings, then turn and move further in a defined direction. Occasionally, this signal is performed towards adults.	Since caretakers move forward during signalling, visual contact between interlocutors is often blocked by vegetation. In virtually all these cases, the signaller re-positions herself within the visual field of the recipient and re-signals.	Caretakers are more likely to elaborate their signalling in interactions with recipients that do not follow them within 30 s from the beginning of signalling than in interactions with recipients that follow them immediately and continuously. Elaboration includes the addition of long-lasting vocalisations, wing movements to vocalisation or producing a different signal named 'beak gaping'.	The duration of signalling behaviour (measured from the beginning of the first signalling event until the end of the last signalling event in the interaction) was longer when communicating to a fledgling that did not follow the signaller within 30 s than when the fledgling followed the signaller immediately and continuously until arrival at a new shelter.
		Interchangeable use of signals	**Visual monitoring of the recipient's behaviour**	
	Goal: to solicit recipient/s to follow the signaller/s.	Caretakers often used the babbler walk signal to solicit fledglings to follow them. Yet they were more likely to replace the babbler walk signal with a beak gaping signal if the fledglings did not follow them (Ben Mocha *et al.*, 2019) and to use this signal first when an urgent response was needed. For example, when a predator was nearby and during late-evening travels to the roosting tree (Y. Ben Mocha, personal observations).	During most communicative interactions, the signaller alternates her head towards the recipient at least once. After these 'checking looks', the behaviour of the signaller (moves forward/ returns to the recipient) was more likely to be in accordance with the recipient's behaviour (follows/does not follow).	
Headstand (Vail *et al.*, 2013)	**Modality:** gestural **Species:** fish – roving coral grouper (*Plectropomus pessuliferus marisrubri*), coral trout (*P. leopardus*)	**Exemplary operational criteria** **Elaboration**	**Selective signalling in the presence of recipients**	
	Description: the signaller orientates herself vertically and head-down while conducting distinct headshakes with pauses between them. **Goal:** to indicate the location of hidden prey	Signallers were more likely to switch to the 'horizontal shimmy' signal when the recipient swam away than in interactions in which the recipient swam towards the pointed location.	Signallers only produce the headstand gesture during hunting attempts in which an octopus was within 10 m of the signaller, but not during hunting attempts in which no octopus was observed nearby.	

(Continues)

Table 3. *(Cont.)*

	to a hunting partner (e.g. morays and octopus).			
Pointing (Kaplan, 2011)	**Modality:** gestural **Species:** bird – Australian magpie (*Gymnorhina tibicen*)	**Exemplary operational criteria** **Selective signalling according to the recipient's knowledge**		
	Description: the signaller aligns her head and body (45° below its resting position) to form a straight line with the beak 'pointing' towards a predator.	Birds pointed when an eagle model was placed in locations that were not visible to other group members but did not point when the model was visible to other group members. In addition, the last bird joining the mobbing group did not point. This counts as evidence against the signal being involuntarily triggered by perceiving a predator or due to higher arousal that is caused by conspecifics' presence.		
	Goal: to indicate the location of a hidden predator to ignorant group members.			
Soft huus, Alarm huus, Waa barks (names of calls after Schel *et al.*, 2013)	**Modality:** vocalisation **Species:** mammals - chimpanzees (*Pan troglodytes*)	**Exemplary operational criteria** **Selective signalling in the presence of recipients (counterevidence)**	**Selective signalling in the presence of specific recipients**	**Selective signalling according to the recipient's knowledge**
	Description: soft huus are short and low-pitched calls. Alarm huus are longer and louder than soft huus. Waa barks are loud and abrupt sounds.	Soft huus were produced after an encounter with a snake model regardless of conspecifics' presence (Schel *et al.*, 2013).	Alarm huus and Waa barks were more likely to be given when a 'friend' of the caller approached the snake model (Schel *et al.*, 2013).	Soft huus were more likely to be given upon approaching of a group member that had not seen the snake and was not likely to hear previous calls than a member that was already informed about the snake (Crockford *et al.*, 2012).
	Goal: all three types of calls are produced in response to a predator encounter. These calls were studied independently by Crockford *et al.* (2012) and Schel *et al.* (2013) with conflicting results (see discussion in Graham *et al.*, 2019)	**Monitoring the attentional state of the recipient** Chimpanzees alternated their gaze between the snake and another chimpanzee at a higher rate during calling bouts than when they were not calling (Schel *et al.*, 2013).	**Temporal dissociation between exposure to the stimulus and signalling** Startle responses occurred less than 0.1 s following exposure to a snake model and were temporally dissociated from soft huus, which were produced 1.7 ± 0.4 s (mean ± SD) after exposure to a snake and 0.9 ± 0.6 s after the end of the startle response. Behavioural dissociation was not tested (Crockford *et al.*, 2012).	

Operational criterion 1c: within a community, inferring the signaller's goal for different signals (step 1 in this scheme). Identifying signals with the same goal, or different goals that are being realised by the same signal. Speculating a role for the implementation of different signals in different contexts. Testing this hypothesis on a new data set.

Examples: babbler walk (Table 3), see also within-community interchangeability in gestural communication of chimpanzees (Hobaiter & Byrne, 2014) and gorillas (*Gorilla gorilla*) (Genty *et al.*, 2009).

Remarks: (*i*) adequate interchangeability of signals provides evidence against the alternative explanation that elaboration may result from "closely related signals [that] share a common arousal-based production mechanism" (Graham *et al.*, 2019, p. 8). If a common arousal-based production mechanism accounts for elaboration, one prediction is that alternative signals will be produced randomly across communicative interactions. By contrast, interchangeability of signals to realise the same goal across interactions – if adequately implemented according to different social and environmental contexts – is counterevidence for this alternative explanation.

(*ii*) Another version of the alternative explanation of Graham *et al.* (2019) is that a common arousal-based production mechanism triggers different signalling behaviours according to different arousal thresholds. In this case, signals would not be produced randomly. This alternative can be ruled out if the social and environmental contexts in which the different signals are used are presumed to induce a similar arousal

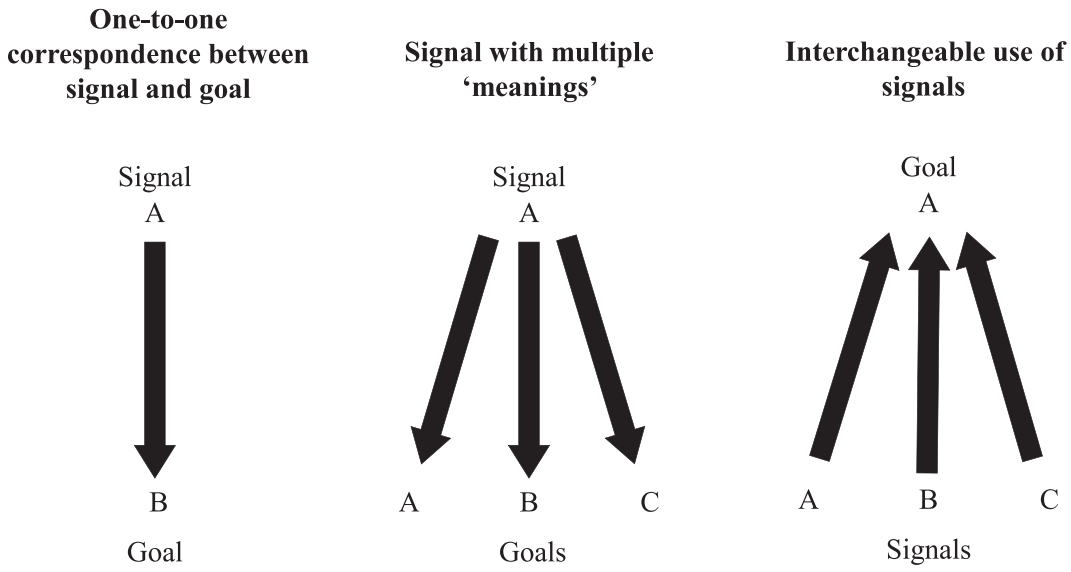

Fig 4. One-to-one *versus* complex correspondence between signals and goals.

level (e.g. signalling is modified according to the availability of the recipient's sensory perception, not according to predator presence; see hallmark 1d).

Counterevidence for adequate interchangeable use of signals being present (examples): (*i*) the same signal is always used to realise the same goal; (*ii*) across communicative interactions, different signals are used in random order to realise the same goal.

Behavioural hallmark 1d: communicative tool use

Using tools for communication provides evidence for the belief that the tool (and therefore the signalling) is a means for realising the goal (for discussion and definition of tool use, see Smith & Bentley-Condit, 2010).

Operational criterion 1d: signallers use a tool as a communicative means to realise a specific goal, while (*i*) the same goal is often realised by other signals (with or without tool use), and (*ii*) the tool is frequently used in non-communicative contexts as well.

Examples: orangutans (*Pongo pygmaeus pygmaeus*) hold leaves against their mouth to enhance a call as an agonistic display towards a human observer (Peters, 2001) and chimpanzees clip leaves loudly for courtship (Nishida, 1980). Both species also use other signals to realise these goals and manipulate leaves for non-communicative purposes.

Remarks: the two clauses in the operational criterion aim to rule out the possibility that the tool use is an integral part of the signal and may thus be genetically hardwired. Namely, the tool is not a necessary (clause *i*), nor sufficient condition (clause *ii*) to realise the goal.

Counterevidence for intentional communicative tool use (example): signallers always use the tool for producing the signal. Different cricket species, for example, manipulate leaves to enhance their calls (Forrest, 1982). However, it remains unclear whether individuals frequently call without these sound-baffle instruments.

Behavioural hallmark 1e: adjustment of signalling behaviour to the sensory perception of recipients

This hallmark demonstrates a belief about how signalling behaviour affects the recipient by manifesting adjustment of signalling to the availability of the recipient's sensory perception (Carpenter *et al.*, 1998; Liebal *et al.*, 2014). Note that first-order intentionality only requires a belief that signalling is a means to affect the recipient. Thus, a signaller can signal intentionally even if she falsely perceives the recipient as an inanimate object and believes that seeing his face while gesturing realises her goal.

In addition, if the adjustments of signalling are qualified as elaboration and are made under situations with a similar arousal level (e.g. all interactions occur in the same context), this hallmark provides evidence against a 'common arousal-based production mechanism' which triggers different signalling behaviours according to arousal thresholds (Graham *et al.*, 2019; see also remarks for operational criterion 1c).

Operational criterion 1e1: testing whether the signaller adjusts her signalling behaviour according to the environmental conditions in different interactions to increase the probability that the signal would be detected by a recipient.

Examples: (*i*) meerkats (*Suricata suricatta*) produce contact calls at a higher rate in environmental conditions in which their group is more dispersed (e.g. call rate is higher during droughts than wet seasons; Toni *et al.*, 2020); (*ii*) when in a forest, signallers access the tree top to produce long-distance calls; but do not call from a raised position when in the open field; (*iii*) adjustment of location: the signaller positions herself in front of the recipient or changes her body orientation to be seen by the recipient before producing a visual signal (Cartmill & Byrne, 2010) or the signaller positions herself within contact distance of the recipient before producing a

tactile gesture. For adjustment of the location to be considered as evidence, it must occur (*i*) in close association with the beginning of signalling (e.g. within a few seconds) and (*ii*) selectively when the signaller has insufficient visual contact with the recipient, but not when she is close and in front of the recipient. Cases in which the recipient is not within the signaller's visual field or range of physical contact and the latter changes her location to be seen by or touch the recipient may be evidence for preparation for signalling (hallmark 2a).

Operational criterion 1e2: testing whether signallers are more likely to adjust signalling behaviour during interactions in which the recipient stops being able to perceive the signal (i.e. withholding signalling behaviour, acting to overcome the barriers to communication or signalling in another modality) than in interactions in which the recipient can perceive the signal continuously.

Examples of real-time adjustment: (*i*) throughout the interaction, the signaller changes her spatial location to ensure that her signalling body parts are within the recipient's visual field (e.g. babbler walk signal in Table 3); (*ii*) audio signals are produced louder when the recipient moves away from the signaller; (*iii*) if visual contact between interlocutors is blocked during the interaction (e.g. due to vegetation), the signaller stops using visual signalling and produces an audible signal; (*iv*) the signaller uses an audible attention-getter to attract the visual attention of a recipient and then starts visual signalling.

Counterevidence for real-time adjustment being present (example): if the recipient stops perceiving the signal, the signaller continues signalling or waits passively, even if the recipient was removed experimentally (tandem running in ants in Table 3).

Operational criterion 1e3: when different signals from different communicative modalities are used to realise the same goal, examining whether signallers choose the signal according to the attentional state of the recipient.

Example: gorillas are more likely to use visual gestures than tactile gestures when the recipient's head is oriented towards the signaller (Genty *et al.*, 2009). However, it is not clear whether these gestures are used to realise the same goal.

Remarks: this also counts as evidence for adequate interchangeable use of signals (behavioural hallmark 1c).

Operational criterion 1e4: adequate usage of attention-getters [i.e. actions that re/attract the attentional state of the recipient to the signaller (Liebal *et al.*, 2014; Fischer & Price, 2017)]: (*i*) the signaller is more likely to use attention-getters in interactions where recipients do not attend to the signaller before she starts signalling/a new behaviour (or if recipients stop attending to the signaller during the interaction) than in interactions in which recipients attend to the signaller at the beginning and throughout the interaction, and (*ii*) various attention-getters are used across communicative interactions of the same signal/to realise the same goal.

Remarks: (*i*) attention-getters may be used before the signaller performs a non-communicative behaviour (e.g. starts travelling away or playing) or before a subsequent communicative signal. It has been disputed however whether this latter usage indeed exists [see critique by Liebal *et al.* (2014); but counterexamples in Nishida (1980), Miklósi *et al.* (2000) and Moura *et al.* (2014)]. We propose that regardless of whether attention-getters are acts aimed to trigger an action in the recipient (Liebal & Call, 2012), signals *per se* (e.g. with 'meaning' of 'look at me'/'join me') or are used to attract the recipient's attention before an additional signal (Nishida, 1980), fulfilling criterion 1e4 demonstrates a belief that adjusting the use of attention-getters helps to realise the desired effect in the recipient (Liebal *et al.*, 2014).

(*ii*) *Examples of attention-getters*: physical: the signaller touches the recipient in a way that is 'mechanically ineffective' to realise her end goal (Pika & Bugnyar, 2011) but is sufficient to draw attention to the signaller. Visual: conspicuous movements of the signaller (e.g. dogs turning their head from their owner to a point of interest: Miklósi *et al.*, 2000). Audible: orange-winged Amazon (*Amazona amazonica*) males vocalise until the female puts her head outside the nest cavity and then use gestural communication (Moura *et al.*, 2014). Multi-modal: stone-throwing by bearded capuchin monkey (*Sapajus* spp.) females towards males (Falótico & Ottoni, 2013).

(*iii*) The second clause in this operational criterion rules out the possibility that the attention-getter is an integral part of the signal/non-communicative behaviour. It also demonstrates further flexibility.

(*iv*) When possible, signallers may prefer to re-position themselves within the visual field of the recipient instead of using attention-getters (Liebal *et al.*, 2014). Interactions in which the signaller re-position herself within the visual field of the recipient just before signalling should thus be excluded from the analysis (see also operational criterion 1e2).

(*v*) Adequate usage of attention-getters can also be shown by their selection in accordance with the social and environmental circumstances. For example, by using less-conspicuous attention-getters when discreet communication is needed (e.g. to initiate 'sneaky copulation') in comparison to when communication is not discreet.

(*vi*) Some scholars have argued that attention-getters may not indicate knowledge about how the signal is perceived (e.g. Butterworth, 1998; Fischer & Price, 2017). Use of attention-getters may rather result from conditional learning that signalling is more efficient when the *signaller* sees the recipient's face (Liebal *et al.*, 2014) combined with learning what type/s of action/s cause the recipient to look at her. However, even if the signaller has a false belief that seeing the recipient's face makes signalling more efficient, her signalling is still qualified as goal-directed since the latter only requires a belief – not necessarily a true belief – that signalling is a means to realise her goal (De Wit & Dickinson, 2009).

In addition, adequate use of attention-getters as examined by criterion 1e4 requires a multi-step conditional learning process. For example, first, a signaller needs to learn that seeing the recipient's face is a precondition for successful communication. Second, the signaller must learn that a specific behaviour (i.e. the attention-getter) causes the recipient to look at her (instead of the signaller re-positioning herself to see the recipient's face). Third, the signaller may learn to

use different types of attention-getters for this propose. Fourth, the signaller needs to select the most appropriate type of attention-getter in each circumstance. Here, we join others (e.g. Liebal *et al.*, 2014) in arguing that as much as a communication system of a species includes various attention-getters from different communicative modalities, multi-step conditional learning becomes a less-simple explanation than intentional use of attention-getters that is based on a belief about how signalling works.

Desire criterion

Behavioural hallmark 1f: adequate persistence of signalling

We consider the investment in signalling (at least in terms of time, but also energy: Forrest, 1982) until a specific change is realised as evidence that this change is adaptive to the signaller. Upon demonstration of additional hallmarks of intentionality, we furthermore consider that the realisation of this change is emotionally desired by the signaller (Carpenter *et al.*, 1998; De Wit & Dickinson, 2009).

Definition of persistence of signalling: the signaller signals (by using one or different signals) until her goal is realised or failure has been clearly indicated.

Operational criterion 1f (adequate persistence of signalling): testing whether the duration of signalling behaviour (measured from when the signaller started to produce the first signal until the end of the last signal aiming to realise the same goal) is shorter in communicative interactions with complying recipients than in interactions with non-complying recipients.

Remarks: (*i*) interactions in which a failure has been clearly indicated to be due to external factors (e.g. predator encounter) should be excluded from the analysis.

(*ii*) Note that this behavioural hallmark examines the presence of a desire, not beliefs. It is, therefore, compatible with the interpretation that persistence of signalling is emotionally driven (Townsend *et al.*, 2017; Graham *et al.*, 2019) and should not be considered as counterevidence for signalling being goal-directed.

(*iii*) For the same reason, this operational criterion examines whether the signaller persists with signalling behaviour *per se*. It is thus irrelevant whether the signaller uses the same or different signals (i.e. elaboration of signalling) throughout the interaction as long as they are used to realise the same goal (Genty *et al.*, 2009).

(*iv*) To be suitable for continuous signals, in which a single signalling event lasts until the recipient responds (e.g. object presentation in Table 3), this operational criterion examines the duration of signalling behaviour rather than the number of signalling events.

(*v*) See Section I.3 for type I error susceptibility of filtering approaches. In addition to this critique, filtering approaches to persistence [e.g. defined as "persisting in goal-directed attempts if the result was not obtained, but ceasing to gesture when it was" (Genty *et al.*, 2009, p. 530)] are susceptible to type II error by not attributing persistence to interactions in which the signaller persisted with signalling for a long time but has terminated signalling when failure to realise her goal was clearly indicated (e.g. interactions 1 and 10 in Fig. 2).

(*vi*) Persistence may not be relevant in signals in which the goal is to transfer information without requiring a behavioural response (i.e. there is no meaning associated with whether recipients are complying or not); for example, constant contact calls that are produced to preserve group cohesion (e.g. meerkats: Toni *et al.*, 2020). In such cases, persistence should not be considered as a necessary condition for intentionality.

Examples: signalling events 1, 9 and 10 *versus* all other interactions in Fig. 2; babbler walk in Table 3.

Counterevidence for adequate persistence of signalling being present (examples): (*i*) the duration of signalling is similar across communicative interactions; (*ii*) signalling behaviour is not significantly longer in interactions with non-complying recipients than it is in interactions with complying recipients.

(3) Third step: inferring voluntary signalling

Potential triggers of involuntary signalling are numerous. Hence, our scheme examines specific triggers, and we encourage researchers to test as many of them as possible. We characterise voluntary signalling as signalling that: (*i*) is not unconditionally executed by perceiving specific external stimuli (i.e. the recipient, his behaviour, signalling by conspecifics, or other pre-defined external stimuli such as a predator or a preferred food item); and (*ii*) is adjusted to complex circumstances in ways that the information according to which the signal is to be executed is unlikely to be entirely encoded in the DNA (Hurford, 2007; Townsend *et al.*, 2017).

One mechanism that is frequently invoked to explain signalling is an arousal threshold that triggers involuntary signalling once it is reached (for review see Fischer & Price, 2017; Graham *et al.*, 2019). While it is evident that arousal may involuntarily affect the form of signalling (Fischer & Price, 2017), humans present an example that one can voluntarily execute a signal also under emotional arousal. Evidence for high levels of arousal is, therefore, not conclusive against voluntary signalling (Liebal *et al.*, 2014). Some signals may be triggered involuntarily by high arousal caused by an external stimulus (e.g. predator encounter), while other signals may only correlate with high arousal since the external stimulus causes arousal and a need to signal (Fig. 5). Improved technologies to measure arousal will help to identify correlations between levels of arousal and signalling (Graham *et al.*, 2019). Nevertheless, they can only provide strong evidence against involuntary signalling if no correlation between arousal and signalling is found. On the other hand, a correlation between signalling and arousal should not be considered as conclusive evidence for involuntary signalling. Behavioural hallmarks of adequately adjustable signalling are, therefore, crucial for distinguishing between voluntary and involuntary signalling.

Execution of signalling is not unconditionally triggered by specific stimuli

Behavioural hallmark 2a: preparation for signalling

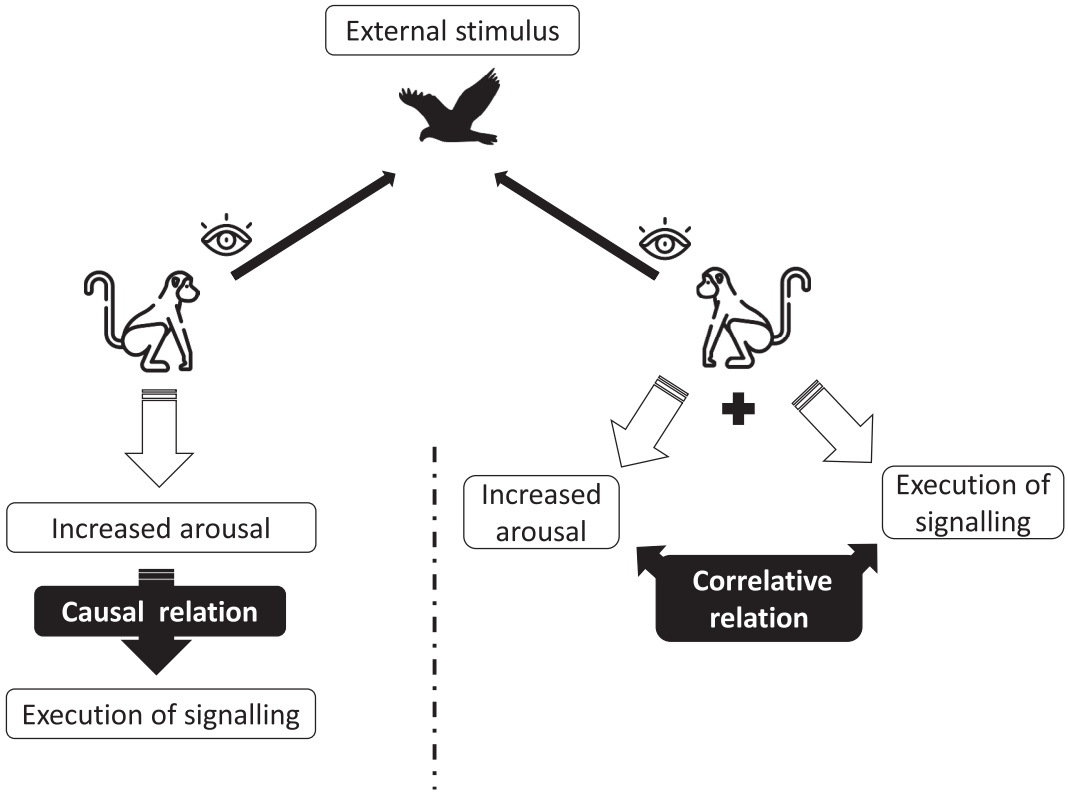

Fig 5. Casual *versus* correlative relationships between arousal and signalling behaviour [icons obtained from Freepik (www.flaticon.com)].

This hallmark demonstrates that the signaller prepares for signalling without perceiving the recipient, his behaviour or a communicative signal from conspecifics.

Operational criterion 2a: in a substantial number of interactions the signaller performs a preparatory act that is necessary for the onset of signalling or for it being successful. These acts need: (*i*) to be performed in the absence of a stimulus from the recipient or signals produced by conspecifics; (*ii*) not to precede all signalling events; and (*iii*) to be frequently used also in non-communicative contexts.

Examples: (*i*) the signaller changes her spatial location to position herself within the visual field of the recipient just before she starts producing a visual signal (Liebal *et al.*, 2004); (*ii*) the signaller moves to where sound travels for long distances (e.g. a tree top over the forest canopy) and soon after her arrival produces long-distance calls.

Remarks: (*i*) the last two clauses in the operational criterion demonstrate that the preparatory act is not an integral part of the signal and not genetically hardwired to be triggered in specific communicative contexts only. For instance, to solicit a group member for mating, Arabian babblers (*Turdoides squamiceps*) often present a common object in their habitat (e.g. a twig), which they also pick up daily in non-communicative acts (e.g. for nest-building; clause *iii*). In addition, signallers often pick up an object in the absence of conspecifics before moving over 15 m to present it to the recipient (i.e. clause *i*) and they may solicit mating by other signals than object presentation (i.e. clause *ii*) (Ben Mocha & Pika, 2019). By contrast, bowerbirds (Ptilonorhynchidae) only collect special items (e.g. blue objects) in bowers and present them to females when they pass by (Uy & Borgia, 2000). The tendency to collect special items may be genetically coded and driven by sexual selection (Uy & Borgia, 2000) and their presentation may be an involuntary response to the appearance of a female.

(*ii*) Changing of location needs to be made immediately before the onset of signalling to avoid the possibility that it was changed for other reasons.

Counterevidence for preparation for signalling being intentional (example): the preparatory act is an unusual behaviour that is only used in this communicative context.

Behavioural hallmark 2b: behavioural dissociations between the external stimulus and signalling

Instinctive responses are executed immediately after exposure to a specific external stimulus [e.g. calling after a predator encounter (Crockford *et al.*, 2012; Wheeler & Fischer, 2012)]. A behavioural, and therefore also temporal, dissociation between exposure to the stimulus and the onset of signalling is thus evidence against instinctive signalling.

Operational criterion 2b: after exposure to an external stimulus, (*i*) the signaller performs at least two different sequential behaviours before she produces the signal (the signal must be

qualitatively different from both these pre-signalling behaviours) and (*ii*) there is considerable within- and/or between-individual variability in the type of pre-signalling behaviour.

Examples: (*i*) when left alone with inaccessible food, dogs perform non-communicative behaviours but vocalise only when their owner enters the room (Miklósi *et al.*, 2000); (*ii*) tandem running in ants and soft huus (Table 3).

Remarks: variation in the behaviours exhibited between the exposure to the stimulus and the tested signal rules out the possibility that the pre-signalling behaviours and the signal are part of a stereotypic response to the stimulus (Crockford *et al.*, 2012).

Counterevidence for behavioural dissociations between an external stimulus and signalling being present: (*i*) the tested signal is always produced immediately after the exposure to the stimulus; (*ii*) the tested signal is always preceded by the same behaviours.

Behavioural hallmark 2c: adequate coupling and decoupling of signals

Coupling and decoupling signals (or a signal and an attention-getter) in ways that are presumed to help realise the signaller's goal demonstrates control about executing and withholding at least one of the signals.

Operational criterion 2c: testing whether – across communicative interactions of the same individual or across different individuals – two signals are produced together and separately in a way that is presumed to increase the likelihood of realising the goal.

Example: in an experimental setting, dogs vocalised and alternated their head between their owner and the location of hidden food. Some dogs synchronised their vocalisation with head-alternation by vocalising only when looking towards the owner, and some dogs by vocalising only when looking at the hidden food (Miklósi *et al.*, 2000).

Behavioural hallmark 2d: selective signalling according to the presence of recipients

This hallmark provides evidence against involuntary signalling by demonstrating that, despite exposure to the stimulus, the signal is selectively produced according to the presence or absence of recipients (i.e. audience effect: Schel *et al.*, 2013).

Operational criterion 2d: testing whether, during exposure to a specific external stimulus (e.g. predator/preferred food item), the signaller is more likely to produce the signal (e.g. alarm/food call) when recipients are present/absent than during exposures in which recipients are absent/present according to whether the signaller's goal is to distract/attract the recipient from/to the stimulus.

Examples: (*i*) headstand signal and soft huus calls in Table 3; (*ii*) common marmoset (*Callithrix jacchus*) produce food calls to attract absent group members (Vitale *et al.*, 2003); (*iii*) bottlenose dolphins (*Tursiops truncatus*) point at containers only when a human diver is present (Pack & Herman, 2006).

Remarks: it has been argued that since arousal levels are usually higher when in a social group compared to when alone, the triggering threshold for arousal-based signalling may only be met in the company of others (Liebal *et al.*, 2014; Graham *et al.*, 2019). However, this alternative explanation does not apply for signals that aim to attract missing recipients (e.g. food calls in common marmosets: Vitale *et al.*, 2003). For signals that are produced in the presence of an audience, evidence that signalling is not produced when informed group members are present will be counter-evidence against this 'socially driven arousal' explanation (see alarm huus and pointing signals in Table 3).

Counterevidence for selective signalling according to the presence of recipients being present (examples): (*i*) the tested signal is produced regardless of the presence or absence of recipients (see soft huus in Table 3); (*ii*) the signaller continues to signal even if the recipient was experimentally removed (see tandem running in ants in Table 3).

Behavioural hallmark 2e: between-communities interchangeable use of signals

Demonstrating that a signal has different functions between communities of the same species provides evidence against the genetic inheritance of signalling (Genty *et al.*, 2009), as well as evidence for flexible usage.

Operational criterion 2e: identify similar signals in different communities of the species, then infer and compare the signaller's goal(s) for the signal in each community (step 1 in this scheme).

Examples: see Genty *et al.* (2009) for a transversal study on within- and between-communities gestural communication of gorillas and Boesch (1995) for different goals realised by the leaf-clipping signal in different chimpanzee communities.

Remarks: demonstrating that a signal is used to realise several goals within a community (behavioural hallmark 1c) and that these goals vary among distinct communities of the species (behavioural hallmark 2e) provides strong evidence against genetic inheritance of the signal and against the mechanistic explanation (for discussion see Genty *et al.*, 2009).

Execution of signalling is not completely genetically determined

Behavioural hallmark 2f: premature termination of signalling behaviour

This hallmark demonstrates violation control over the termination of signals that consist of a specific sequence of different actions.

Operational criterion 2f: testing whether the realisation of the signaller's goal (or its onset) is followed by termination of signalling before completion.

Counterevidence for premature termination of signalling behaviour being present: once started, the entire sequence of actions is executed regardless of the recipient's behaviour.

Behavioural hallmark 2g: signalling is not sex-specific

This hallmark examines whether a signalling behaviour is exclusively produced by males or females in species with no anatomical limitations for both sexes to produce the signal and where both sexes would seem to benefit from using it. Since intentionality is a general cognitive mechanism, sex-specific signalling is counterevidence for intentionality and supports the view that the behaviour is genetically hardwired.

Example: in species where both parents provide similar parental care, both sexes would benefit from producing a signal that solicits offspring to follow them (see babbler walk signal in Table 3).

Remarks: (*i*) the performance of a signal by both sexes does not provide evidence in favour of intentionality since signalling can still be genetically hardwired at the species level. This hallmark can thus only provide evidence against intentional signalling.

(*ii*) Due to anatomical differences, different signals may be more suitable for males and females for realising the same goal and this should not count as counterevidence for voluntary signalling. For example, females of some bird species solicit mating by bending over in front of the male (Davies *et al.*, 1996; Ben Mocha & Pika, 2019). As this posture is a pre-condition to enable mating, imitating it may be a more efficient signal for females, but not for males.

Behavioural hallmark 2h: selective production/withholding of signalling according to complex conditions

Here, complex conditions are unlikely to be entirely encoded in the DNA (Hurford, 2007). In the following, we present two examples of such conditions.

Operational criterion 2h1: audience effect: testing whether the signal is more likely to be produced and/or withheld under specific audience composition [e.g. according to dominance rank, kin relation, or degree of social bond (Miklósi *et al.*, 2000; Schel *et al.*, 2013)].

Remarks: (*i*) withholding signalling in the presence of specific recipients can be shown, for instance, by documenting termination of signalling when specific individuals appear.

(*ii*) it is important to rule out the possibility that the presence of specific individuals involuntarily triggers or prevents the tested signalling behaviour. For example, by showing that the signal is not produced in all situations in which these individuals are present (Schel *et al.*, 2013) or that dominant group members do not withhold signalling because they are being attacked by subordinate group members (see object presentation in Table 3).

(*iii*) This operational criterion may not rule out the alternative explanation that signalling is triggered by higher arousal levels in specific social contexts since, for example, the presence of higher-ranking individuals may be more stressful for the signaller (Liebal *et al.*, 2014).

Examples: (*i*) dogs gaze and vocalise when their owner is present (Miklósi *et al.*, 2000); (*ii*) in chimpanzees communities where leaf clipping is used to initiate copulation, signallers terminate signalling upon arrival of a more dominant individual (Nishida, 1980; Matsumoto-Oda & Tomonaga, 2005); (*iii*) alarm huus in Table 3.

Counterevidence for complex audience effect being present: soft huus in Table 3.

Operational criterion 2h2: selective signalling in accordance with the signaller's perception of the recipient's behaviour and/or knowledge (Kaplan, 2011; Crockford *et al.*, 2012).

Examples: alarm huus, waa barks and pointing signals in Table 3.

Remarks: this operational criterion can provide evidence against the alternative explanation that signalling is triggered by a higher arousal level in social contexts (Liebal *et al.*, 2014; Graham *et al.*, 2019). See also remarks for behavioural hallmark 2d, operational criterion 2h1, and pointing in Table 3.

Form of signalling is not completely genetically determined.

Behavioural hallmarks 1b, 1d and 1e as described above.

(4) Fourth step: signalling behaviour realises the signaller's goal

Behavioural hallmark 3: signalling is likely to change the recipient's behaviour in ways that are conducive to realising the signaller's goal

Operational criterion 3: post-signalling, the recipient is more likely to change her behaviour in ways that are conducive to realising the signaller's goal, in comparison to when the signaller performs a 'control behaviour' (i.e. a similar behaviour to the tested signal; e.g. a non-communicative action that is physically similar to the tested gesture).

Example: object presentation in Table 3.

III. DISCUSSION

The theoretical framework of our scheme follows the traditional contrast between the 'mechanistic' and 'intentional' mechanisms that may underlie signalling behaviour (Dennett, 1983; Call & Tomasello, 2007; Liebal *et al.*, 2014). Lacking direct access to these mechanisms, the scheme examines their manifestation in behaviour and differentiates between more- and less-adjustable signals and communicative modalities. Hence, even if one rejects the ability to differentiate between these underlying mechanisms, we argue that our differentiation between more- and less-adjustable signals is an objective alternative to categorising signalling behaviours of animals according to their similarity to human communication. Furthermore, despite not presenting a conclusive test for inferring intentional signalling in animals, our scheme and each of its operational criteria are significantly more rigorous than those traditionally used to infer intentionality in pre-linguistic children [for examples, compare with Bates (1979), Coggins & Carpenter (1981) and Carpenter *et al.* (1998)].

Identifying species that are incapable of intentional signalling (and in which communicative modalities) is an integral part of generating and testing hypotheses about the evolution of intentional communication. We therefore call for greater efforts to publish negative results. Since a species can produce intentional and non-intentional signals, we propose considering a species as incapable of first-order intentional signalling in a specific modality upon evidence of non-intentional signalling in two signals from this modality.

We suggest three directions in which the presented scheme can be expanded. First, other communicative modalities than the visual and auditory may be used intentionally, and the expansion of the scheme to these modalities is important

for enabling research on diverse taxa (e.g. olfactory signalling in the Bovidae).

Second, the definition of first-order intentional signalling ('voluntary signalling in pursuit of a cognitively represented goal') can be generalised to non-communicative acts by replacing 'signalling' with 'acting'. Comparing actors' behaviour between successful and unsuccessful attempts to realise a goal (instead of interactions with complying *versus* non-complying recipients) would then test first-order intentionality in non-communicative acts (e.g. food caching and food sharing: Burkart & van Schaik, 2020).

Third, some behavioural hallmarks in the scheme also characterise ostensive signalling (e.g. attention-getters; for discussion see Fischer & Price, 2017). That is, when the signaller also expresses the very fact of having communicative intentions (Grice, 1957). Parts of this scheme can thus be integrated with previous ideas (e.g. Sievers & Gruber, 2016; Ben Mocha & Pika, 2019) to develop a framework to infer ostensive signalling in animals.

IV. CONCLUSIONS

We present a unified, operational-level scheme with 16 behavioural hallmarks and 20 operational criteria to infer first-order intentional signalling following the three conditions proposed by Townsend *et al.* (2017). In so doing, we aim to facilitate rigorous and systematic comparison of first-order intentional signalling across studies, species and communicative modalities.

Even rigorous hallmarks of goal-directed and voluntary signalling can be explained by alternative mechanisms (Dennett, 1983; Liebal *et al.*, 2014). Furthermore, human signalling occasionally lacks some hallmarks of intentionality (Bates, 1979; Coggins & Carpenter, 1981) or is performed in a non-intentional manner (De Wit & Dickinson, 2009). We thus urge the presentation of 'converging' evidence before concluding that a species is capable of first-order intentionality (Townsend *et al.*, 2017; Graham *et al.*, 2019). Our scheme facilitates this in two ways. First, by testing multiple hallmarks, it can establish accumulative evidence for adjustability that makes first-order intentionality the most plausible mechanism for the examined signal. Second, by applying this scheme to more than one signal from the same communicative modality, it can investigate whether such adjustability is the result of a general cognitive mechanism of that species.

Testing as many operational criteria as possible comes with the risk of finding a positive result by chance (i.e. type I error). This is particularly likely to happen when intentionality is assigned if signalling fulfils at least one out of several behavioural hallmarks (e.g. Cartmill & Byrne, 2010; Hobaiter & Byrne, 2014). We therefore highlight the importance of reporting negative evidence for the hallmarks tested, thereby promoting a transparent and balanced evaluation of the overall evidence for intentionality at the signal level.

The presented scheme is not meant to be exhaustive. Rather, comparative research will benefit from the addition of diverse hallmarks and operational criteria to infer intentionality. Throughout the scheme, we thus discuss core rationales (and limitations) in order to facilitate suggestions of further behavioural hallmarks and case-specific modifications while maintaining these core rationales and valid comparison across studies.

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